Insulation Performance Beneath Roads and Airfields in Alaska

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In 1968, the Alaska Department of Highways constructed its first experimental installation of expanded plastic foam for frost heave control at a site 11 mi south of Anchorage. This was followed, in 1969, by construction of both the first insulated roadway section over permafrost in North America at a site near Chitina, and the first insulated airfield runway at Kotzebue. Since that time, six additional roadway sections on permafrost, totalling 3.6 lane-mi, have been insulated by the Alaska Department of Transportation, along with four additional airport installations. Applications of insulation for frost heave control have been numerous, totalling 11 lane-mi. Materials used for subgrade insulations have been primarily extruded-expanded polystyrene foam (Dow's Styrofoam HI and UCI Foamular) with one installation of polyurethane foam and three of molded polystyrene beadboard. Evaluations of the long-term thermal performance of these installations have included sampling and testing of the insulations to determine the retained thickness, thermal conductivity, and compressive strength properties. Based on these observations, foamed-in-place polyurethane insulation is not accepted for use as a subgrade insulation by the Department of Transportation, whereas extruded polystyrene insulation has demonstrated superior performance and longevity. Molded polystyrene beadboard insulation layers have given acceptable performance, but must be installed at a thickness 30 percent to 50 percent greater than the extruded polystyrenes to provide comparable thermal performance. Comparisons were made between measured late summer permafrost thaw depths for insulated airfields, and calculated thaw depths using the Modified Berggren calculation method and actual site soil and insulation properties. These comparisons demonstrated that this method of calculation results in calculated thaw depths slightly greater than the actual values, but provides reasonable values for a conservative design.

In 1967, the Alaska Department of Highways constructed its first experimental installation of expanded plastic foams for frost heave control at a site 11 mi south of Anchorage. This was followed, in 1969, by construction of both the first insulated roadway section over permafrost in North America at a site near Chitina, and the first insulated airfield runway at Kotzebue. Since that time, six additional roadway sections on permafrost have been insulated by the Alaska Department of Transportation, along with three airport runways and one taxiway. Applications of insulation for frost heave control have been numerous, particularly in the Anchorage-Wasilla area, where varying glacial deposits can result in severe differential frost heaving. Insulation layers are also frequently used beneath roadway crossings of buried water and sewer lines and subdrain systems. Materials used for subgrade insulations have been primarily extruded-expanded polystyrene foam (Styrofoam HI and UCI Foamular 400) with one installation of polyurethane foam and three of molded polystyrene beadboard.

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To evaluate the long-term thermal performance of these installations, air and gravel temperature monitoring instrumentation, consisting of thermocouples, thermistors, and chart recorders were installed at five sites. Temperatures have been monitored on a monthly basis for various periods at the different sites, the longest period being 16 yr at the Chitina permafrost site. In September of 1984, insulation samples were taken from selected road and airfield sites and tested for thermal conductivity and moisture absorption to analyze their long-term performance. At the permafrost insulation sites, soil moisture contents and thaw depths were also measured. Thaw depth calculations were then made by the Modified-Berggren calculation method to compare predicted versus actual thaw depths.

Roadway and airfield insulation sites constructed by the Alaska Department of Transportation and Public Facilities to control frost heaving or permafrost thaw settlements are listed in Tables 1 and 2 and locations are shown in Figure 1.

GENERAL SITE PERFORMANCE OBSERVATIONS

Frost Heave Sites

The first sites insulated in 1967 for frost heave control were monitored for 3 yr and their performance was documented *(1)*. The basic conclusions of this work were that the foamed-in-place polyurethane insulation used was not adequately resistant to water absorption, even when coated with asphalt, and it was not recommended for further roadway insulation applications. The extruded polystyrene, however, performed very well and was recommended for future frost heave control applications. For these instrumented sites, the Modified Berggren calculation method predicted freeze depths beneath the insulation with reasonable accuracy with a tendency to slightly overpredict these depths for thick insulation layers. This study also demonstrated that the full extent of the frost heave problem area must be known before designing the length of the insulation section to avoid creating heave bumps at the ends of the insulation. Based on data from these sites, a composite thermal design approach is recommended, with specified thicknesses of non-frost-susceptible gravels or sands placed above and below the insulation layer. By allowing freezing to penetrate into gravel fill placed beneath the insulation, the most economical design can be achieved. A depth of cover of at least 18 in. of gravel and pavement above the insulation is recommended to provide tolerable wheel-load stresses on the insulation. The problem of

TABLE 1 ANCHORAGE AREA AND PARKS HIGHWAY—FROST HEAVE CONTROL SITES

Year Built	Site or Route	Specific Location	Insulation Type	Thickness Inches	Cover Depth Inches	Length Lane Miles
1968	Seward Hwy	MP 114.9	FIP Urethane	2	18	0.036
1968	Seward Hwy	MP 115.1	Styrofoam HI	3	18	0.042
1970	Parks Hwy	MP 75.0	Styrofoam HI	4	18	0.055
1970	Parks Hwy	MP 84.2	Styrofoam HI	4	18	0.097
1971	New Seward	Tudor-East	Styrofoam HI	3	24	0.909
1971	Talketna Spur	MP 9.3	Styrofoam HI	3	18	0.170
1971	Parks Hwy	MP 117.0	Styrofoam HI	4	18	0.776
1975	Minnesota Drive	15 ST. Jct.	Styrofoam HI	4	27	0.076
1975	New Seward	Tudor-East	Styrofoam SM	3	24	1.310
1978	Parks Hwy	MP 36.7	Styrofoam HI	4	60	0.110
1981	Minnesota Dr.	At Dimond	Sty. Beadboard	4	24	0.760
1983	Northern Lights	Goose Lake	Styrofoam, HI	4	44	0.833
1984	Minnesota Ext.	At Dimond	Sty. Beadboard	4	36	2.340
1985	A-Street	@ 23 St.	Styrofoam HI	4	47	0.303
1985	A-Street	@ 15 St.	Styrofoam HI	4	47	0.530
1984	Parks Hwy	Panguingue	Styrofoam HI	4	24	0.038
1986	Parks Hwy	293.4-297	Foamular 400	2&4	42	2.650

TABLE 2 PERMAFROST INSULATION SITES

Year Built	Site or Route	Specific Location	Insulation Type	Thickness Inches	Cover Depth Inches	Length Lane Miles
1969	Chitina N.	MP 27	Styrofoam HI	2&4	60	0.070
1973	Parks Hwy	MP 231.8	Styrofoam HI	4	54	0.170
1974	Parks Hwy	Alder Ck. S.	Styrofoam HI	4	54	0.125
1974	Parks Hwy	Alder Ck. N.	Styrofoam HI	4	120	0.072
1979	Farmer's Loop	Fairhill Rd.	Poly. Beadboard	4	48	0.077
1985	Canyon Creek	Rich. MP 299	Styrofoam HI	3	33	1.061
1986	Edgerton Hwy	MP 1.3-7.0	Styrofoam HI	2	42	2.080
	Insulated Airfield Runways on Permafrost					
1969	Kotzebue Airport		Styrofoam HI-35	4	42	1900'
1981	Buckland Airport		Styrofoam HI-35	6	36	2400'
1981	Deering Airport		Styrofoam HI-35	2	30	2700'
1985	Nunapitchuk Airport		Styrofoam HI-60	6	30	2750'
1985	Deadhorse Taxiway B		Styrofoam HI-60	2	56	360'

differential frost formation on the road surface in insulated areas is lessened by increased depths of burial.

As shown in Table 1, the depth of cover over frost heave insulation has varied from 1½ to 5 ft. Surface frost forms more quickly on bridge decks and above insulated areas than on normal road structures. The resulting decreases in traction have recently (in 1985) been treated by installing rubber-modified asphalt pavement surfacing above the insulated areas at the A-Street, New Seward at Tudor, and Canyon Creek sites. The benefits of this pavement type have been investigated by Esch *(2)*. If this treatment proves successful in eliminating icing problems, it may permit cover depths above the insulation to be reduced to the 18-in. minimum required by stress considerations.

Permafrost Sites

The Chitina insulated road site, constructed in 1969 over relatively warm (+30°F) permafrost, has generally performed well, with full annual refreezing of the soils beneath the roadway and a long-term subroadway permafrost temperature of 31.0°F to 31.5°F. However, the gravel side slopes of the embankment, which are insulated by snow in winter and exposed to direct sunlight in summer, have caused progressively deeper annual thawing, averaging about 3 in./yr into the permafrost beneath the slopes. This has resulted in progressive slope sloughing and cracking in the shoulder areas *(3)*. By comparison, the adjacent uninsulated roadway areas have continued to settle annually at a rate of 0.1 to 0.2 ft/yr. Side slope thawing movements have been similar in insulated and uninsulated areas, and some settlements related to stress-related creep of the warm permafrost foundation soils continue to be noted in all areas of this roadway.

The performance of most other insulated permafrost roadway sites has been similar to that at Chitina, with full annual refreezing occurring beneath the insulated traveled roadway area, but with progressively deeper annual thawing and related movements of the side slope areas.

Cover depths used over permafrost insulated layers tend to be greater than for frost heave control, primarily because of construction traffic considerations. Permafrost insulation has generally been designed based on borings and installed during embankment construction. The heavy construction equipment used requires care to avoid crushing. By contrast, frost heave insulation sections have nearly always been designed as corrective measures for heaves on existing roads, where minimizing the depth of excavation is of major concern.

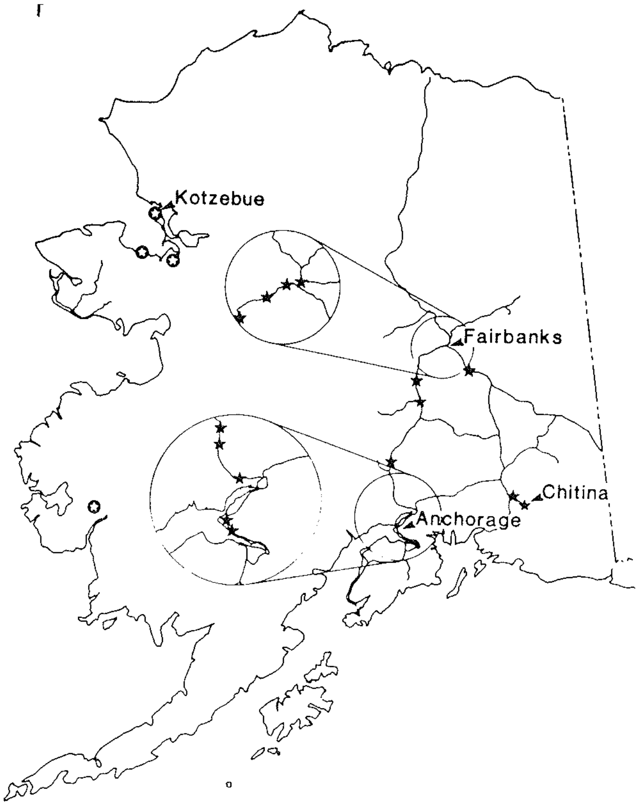

FIGURE 1 Location of insulated roadways (✪) and airfields (✯) constructed by Alaska Department of Highways and Department of Transportation.

FIELD SAMPLING AND INSULATION TESTING PROGRAMS

Insulation sampling and testing to measure moisture absorption and compression under field conditions has been done at various times and locations to verify the field performance of the buried insulation layers.

Polyurethane Foams

The most extensive testing of polyurethane road insulation samples was in September 1972 at an Arco Chemical road test site near Prudhoe Bay. At that location, urethane foam board samples taken from beneath a permafrost area roadway, after 2 yr of exposure on a wet tundra foundation, demonstrated moisture contents as high as 30 percent by volume or 1000 percent by weight of the dry foam. Unfortunately, data from this polyurethane field test and sampling program were never published because of the unexpectedly poor insulation performance. This investigation was followed in March of 1979 by a foamed-in-place urethane insulation sampling program at the Potter frost heave insulation test site located near Anchorage *(1)*.

At Potter, several samples were obtained from the wheelpath areas after 12 yr of insulation exposure to traffic and the environment. In addition, two samples were obtained from an extension of the urethane insulated area, placed in 1974. Six representative samples of the 1967 insulation were tested for absorbed moisture and had total moisture contents, calculated as percent water by volume, ranging from 3.1 to 72.0 percent.

Thickness measurements were made in many locations that were believed to be within the original (1968) 2-in. insulation area, and an average thickness of approximately 0.9 in. was noted. No foam thicker than 1.2 in. could be found. Exact thickness comparisons are not possible because of the somewhat random thickness obtained from in-place foaming of urethanes, but measurements at the time of placement indicated an average thickness very close to 2 in. Many areas of thickness as low as $^1/_2$ in. were noted and foam in these areas was generally nearly saturated. This foamed-in-place urethane had an average compressive strength of 31.5 psi when placed in 1967. All data indicate that this foam insulation failed by moisture absorption and compression under field service.

By contrast to the generally compressed and relatively wet state of the 1968 urethane foam, the samples from the 1974 extension appeared to be in excellent condition, maintaining some hope that polyurethane foams may perform reasonably well under direct soil burial conditions. Two samples of this insulation had dry densities of 2.0 and 2.1 pcf, absorbed water contents of 1.3 and 1.0 percent by volume, and average compressive strengths of 28.1 and 26.3 psi at 5 percent strain. The strength and moisture properties of this product appeared satisfactory for acceptable performance in direct burial. Unfortunately, this entire test site was excavated in 1979 so the long-term performance of this material could not be followed. The reasons for the good performance of this foam compared with the failure of the two urethanes previously mentioned could not be determined.

Polystyrene Foams

Field samples of in-service polystyrene subgrade insulations were taken in September of 1984 from various road and airfield sites in Alaska. Samples were typically taken from hand-dug test pits located at the edge of the asphalt pavement. All samples were sealed in Ziplock bags and subsequently tested for moisture absorption and wet thermal conductivity, using the thermistor bead technique detailed by Atkins *(4)*.

In this method a single thermistor bead, approximately .04 in. in diameter, is inserted into the insulation board and a controlled electrical current is applied to cause resistance heating of the thermistor. Periodic readings are taken of temperature rise versus time, from which the thermal conductivity can be calculated. Multiple readings at various depths within a foam sample are used to obtain a profile of conductivity versus depth, from which an average value is calculated. Results are consistent and agree well with the more precise laboratory "guarded hot plate" method.

Two of these sites, the Fairbanks area Fairhill Access Road, constructed in 1979 *(5)* and Anchorage's Minnesota Extension—Phase I, constructed in 1981, contain white polystyrene beadboard, with a compressive strength greater than 30 psi. This product is molded in blocks from pre-expanded foam beads. The remaining sites were all insulated with blue Styrofoam HI insulation, which is foamed in an extrusion process. Results of all testing are included in Table 3 and averages for each site are shown in Figure 2.

The best-fit trend lines (Figure 2) showing the relationships between moisture content and thermal conductivity for both extruded and molded foam boards were found to be in excellent

TABLE 3 POLYSTYRENE INSULATION TEST RESULTS

Site	Layer	Thickness	Foam Density (pcf)	Insulation Type	% Water/Vol	Kavg.	Year Placed
Kotzebue	Top	2"	2.39	E	2.38	0.214	1969
Kotzebue	Bottom	2"	2.14	E	0.89	0.194	1969
Buckland	Top	3"	2.26	E	0.41	0.204	1981
Buckland	Bottom	3"	2.10	E	0.23	0.208	1981
Deering	Single	2"	2.16	E	1.37	0.204	1981
Chitina	Top	2"	2.56	E	0.71	0.237	1969
Chitina	Bottom	2"	2.63	E	0.88	0.225	1969
Chitina	Single	2"	2.63	E	1.54	0.216	1969
Bonanza Creek	Single	2"	2.24	E	1.48	0.247	1974
Bonanza Creek	Single	2"	2.83	E	2.38	0.248	1974
Fairhill	Single	4"	2.44	BB	1.18	0.278	1979
Fairhill	Top	2"	2.17	E	0.50	0.222	1979
Fairhill	Bottom	2"	2.27	E	0.20	0.213	1979
Fairhill	Single	4"	2.98	BB	1.48	0.289	1979
Minnesota Dr.	Top	2"	2.46	BB	5.88	0.358	1981
Minnesota Dr.	Bottom	2"	2.71	BB	2.90	0.266	1981
Geneva Woods	Single	3"	---	E	0.64	---	1970
Geneva Woods	Single	3"	---	E	0.53	---	1970

Type E = Extruded Expanded Foam
Type BB = Molded and Cut Beadboard Foam

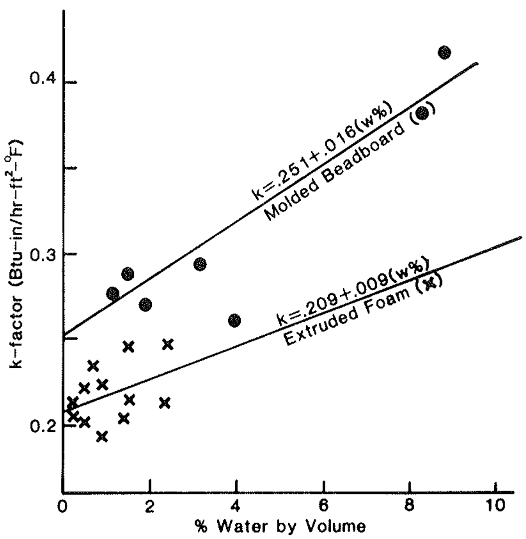

FIGURE 2 Moisture contents and thermal conductivities at 72°F of polystyrene insulation samples from roads and airfields in Alaska.

agreement with other data from laboratory tests at higher moisture contents *(6–9)*. All samples were within 5 percent of the nominal thickness, indicating that compression and creep with time is not a problem.

The extruded styrofoam insulation board, sampled from six sites with a maximum age of 15 yr and averaging 9.5 yr of service, had an average moisture content of 1.16 percent by volume. Thermal conductivities (K) of these samples average 0.22 Btu-in./hr-ft^2-°F at 72°F. Maximums were a moisture of 2.38 percent and a K of 0.248. By comparison, the molded beadboard samples, from sites 3 and 5 yr old, had an average moisture of 2.9 percent and an average K-factor of 0.30. Maximum values for the beadboard were 8.7 percent moisture and a K of 0.42. When analyzed by a standard statistical approach, the long-term minimum R values/in. expected at the 95 percent confidence level are 3.9 for extruded polystyrene foam and 2.6 for high-strength molded polystyrene beadboard. This results in a thickness ratio for equivalent performance of 1.5 in. of molded to 1.0 in. of extruded foam. If this ratio is based on average rather than minimum R values, a thickness ratio of 1.36 to 1 is indicated; however, a ratio this low would be unfair to extruded foams, which are more consistent and better able to resist moisture gains and R-value losses with time in service.

THAW DEPTHS: INSULATED AIRFIELDS ON PERMAFROST

Observations of the thaw depths were made between September 4 and 6, 1984, at the three insulated airfields investigated in this study, and soil moisture contents were measured at intervals to permit comparisons between thaw depth prediction methods and actual field values.

Thaw depth calculations were made for each of these runways using the actual measured soil and insulation properties, the Modified-Berggren calculation method as programmed by Braley *(10)*, the recorded Kotzebue air thawing index of +1480°F-days, and surface n-factors of 1.70 for Kotzebue (paved) and 1.30 for the other (unpaved) sites *(11)*. These calculations overpredicted the thaw depths by 0.2 to 0.5 ft, as shown in Table 4, indicating that this calculation method is conservative for designing insulation layers on cold ($T > 30$°F) permafrost.

SUMMARY

Since 1967, the Alaska Department of Transportation has insulated a total of 14.7 lane-mi of roadways and 9,750 ft of airfield runway to control frost heaving and permafrost thawing. Insulation materials used have included foamed-in-place polyurethanes, molded polystyrene beadboard, and extruded-expanded polystyrene foam.

Polyurethane foams have varied greatly in field performance, with high moisture absorption and compression failure

TABLE 4 MEASURED AND PREDICTED TOTAL THAW DEPTHS FOR 1984 FOR INSULATED AIRFIELDS ON PERMAFROST (based on modified Berggren calculation method using measured soil moistures and insulation thermal properties)

Site	Thawing Index (F-Days)	Surface N-Factor	Insulation Depth	Measured Thaw Depth (ft)	Predicted Thaw Depth (ft)
Kotzebue	1480	1.70	3.5'	4.7'	4.9'
Buckland	1480	1.30	3.3'	3.8'	4.3'
Deering	1480	1.30	2.3'	2.8'	3.2'

noted at two of three sample locations. For this reason polyurethane foams are not presently accepted by the Alaska Department of Transportation for use beneath roads or airfields.

Based on observations from field sampling of the insulations after various exposure periods, the superiority of extruded-expanded polystyrene foam is evident after as much as 15 yr of service. Molded polystyrene beadboard products, evaluated after 3 to 5 yr of service, were somewhat less resistant to moisture absorption in the subroadway environment. To provide equivalent long-term thermal performance under soil burial conditions, beadboard insulation thicknesses should be 30 to 50 percent greater than extruded foam thicknesses. When installed beneath roads and airfields, the functional design life of extruded foams is projected to be much greater than 20 yr.

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